A capillary discharge-preformed argon plasma waveguide for a coherent soft x-ray source

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1. Introduction

The interaction of an ultrashort, intense laser pulse with a wide variety of optical waveguides has been demonstrated in various applications, including electron acceleration [1], non-linear wavelength conversion [2], high-order harmonic generation [3,4], etc. We report the argon plasma waveguide produced by an alumina capillary discharge to guide ultrashort laser pulses at a laser intensity of the order of 10^{16} W/cm^2. A one-dimensional magnetohydrodynamics (MHD) code was used to evaluate the degree of ionization of Ar in the preformed plasma channel. The spectrum of the stable propagated laser pulse in the argon plasma waveguide was not modified and was well reproduced in a particle-in-cell (PIC) simulation.

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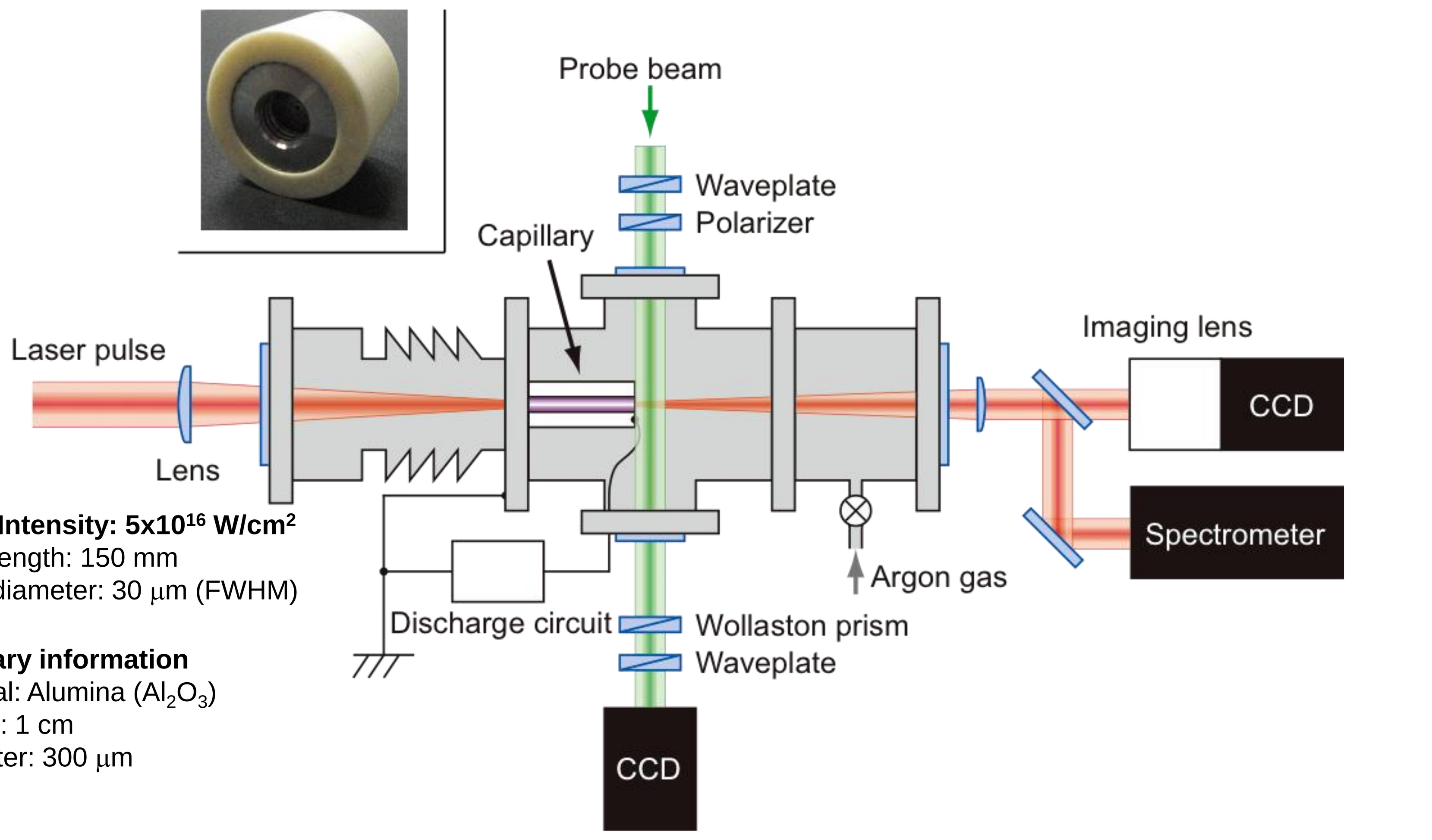
2. Experimental setup



Laser Intensity: 5x10^{16} W/cm^2
Focal length: 150 mm
Focal diameter: 30 μm (FWHM)

Capillary information
Material: Alumina (Al_2O_3)
Length: 1 cm
Diameter: 300 μm

Fig. 1. Experimental setup.

Laser parameter

Ti:Sapphire laser

Wavelength: 800 nm
Maximum pulse energy: 40 mJ
Pulse width: 160 fs (FWHM)
Repetition rate: 10 Hz

Discharge parameter

Maximum discharge voltage: 20 kV
Maximum discharge current: 200 A
Capacitance: 2 nF

Interferometer system

Nomarski interferometer

Spatial resolution: less than 10 μm
Contrast of the interferogram: 0.75

3. Results & numerical simulation

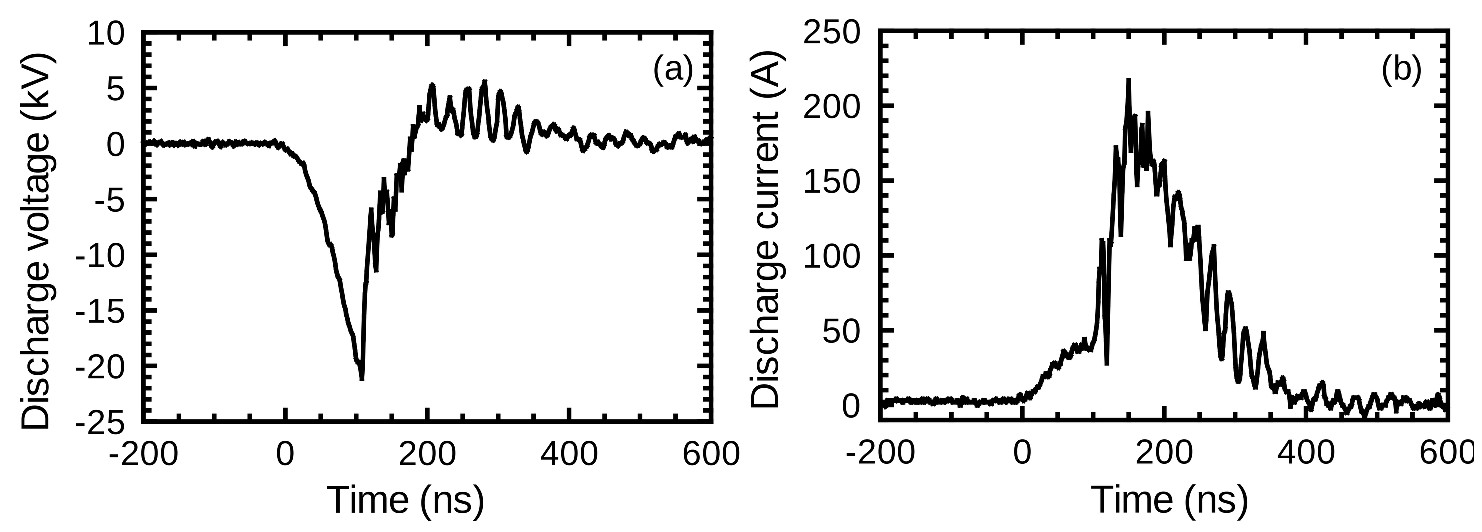


Fig. 2. Temporal waveforms of the discharge voltage (a) and current (b), respectively.

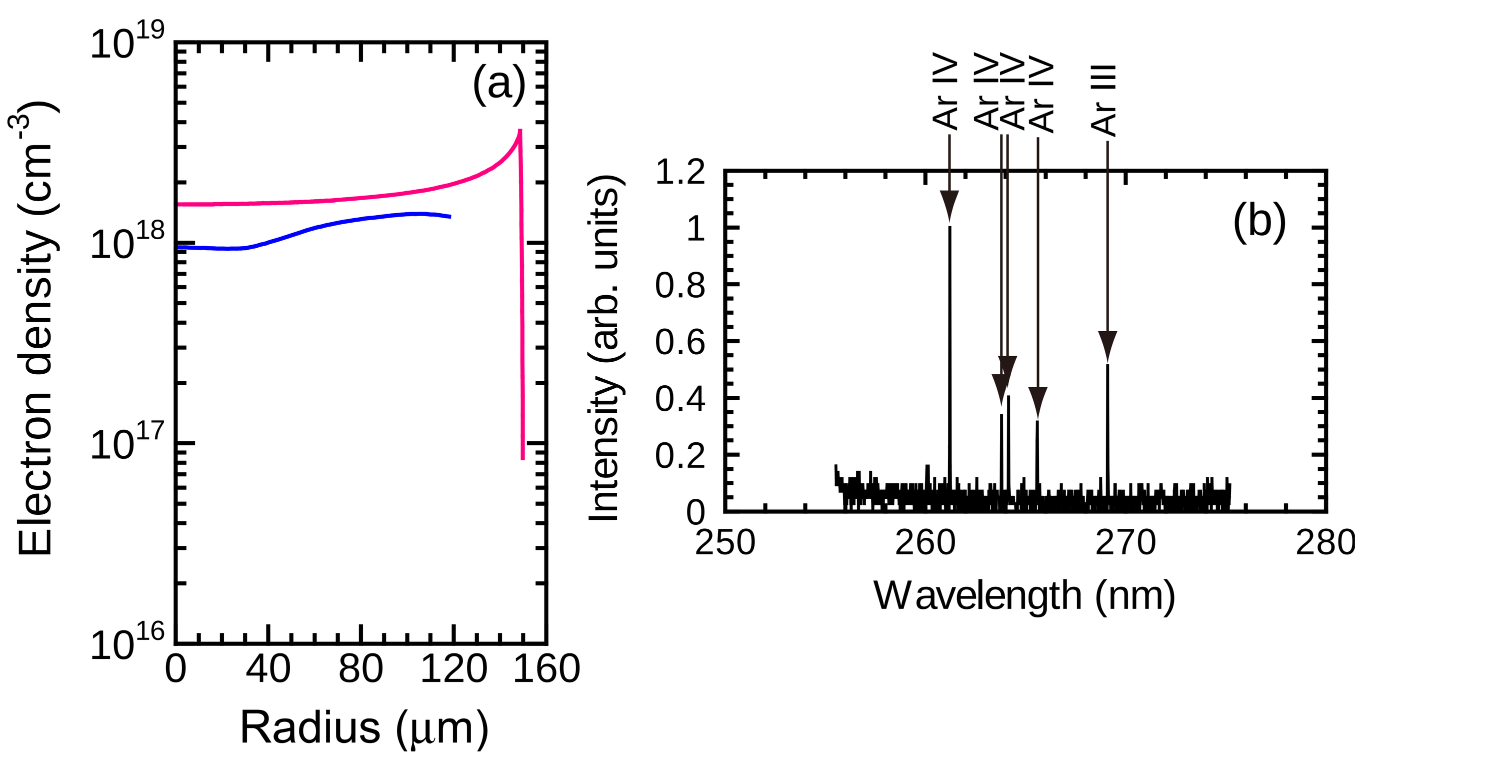


Fig. 3. (a) The radial profile of the electron density, measured at the capillary exit (blue), and obtained in MHD simulation (red). (b) Time-integrated spectrum of the visible emission from the plasma jet.

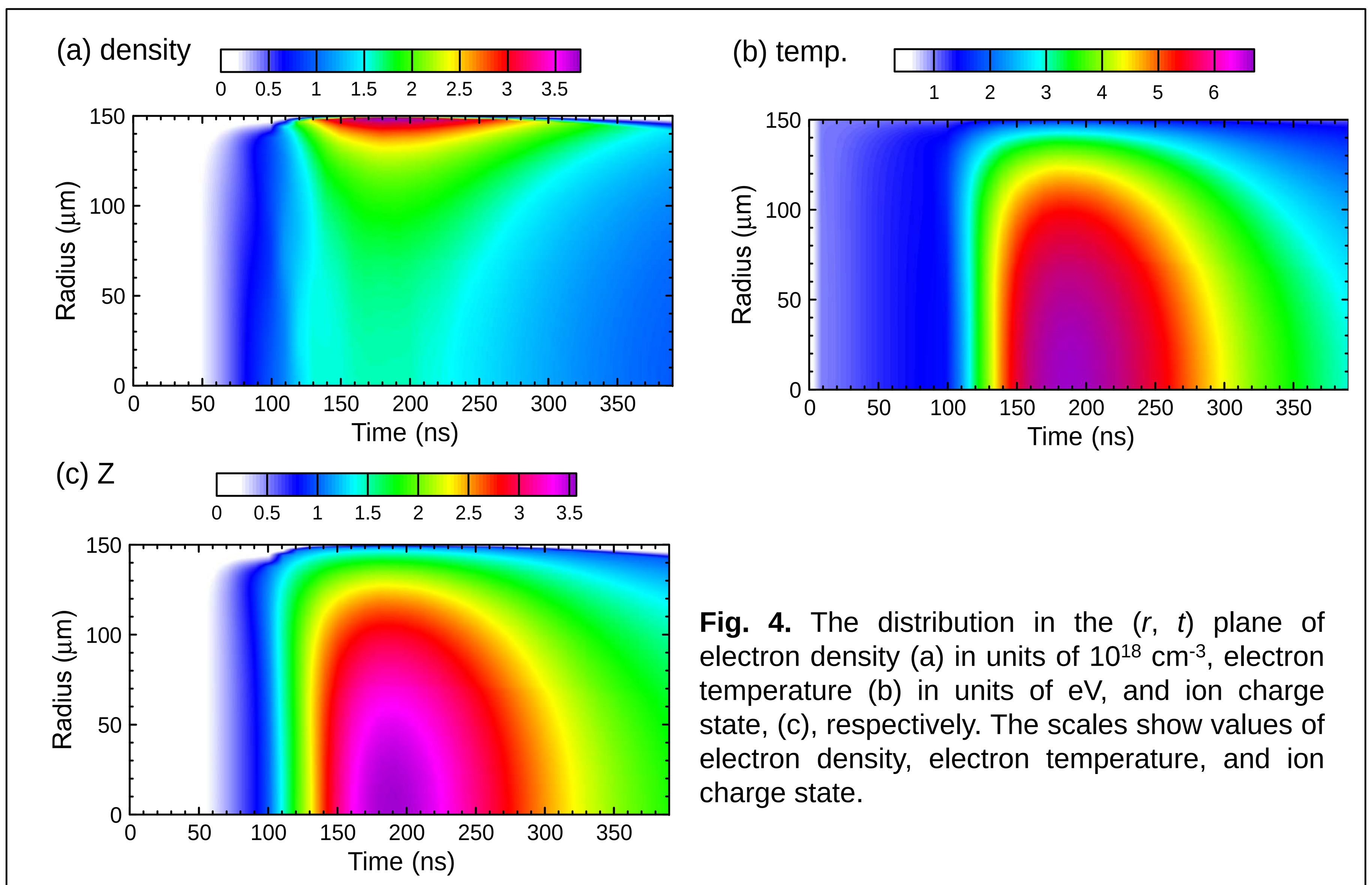


Fig. 4. The distribution in the (r, t) plane of electron density (a) in units of 10^{18} cm^{-3}, electron temperature (b) in units of eV, and ion charge state, (c), respectively. The scales show values of electron density, electron temperature, and ion charge state.

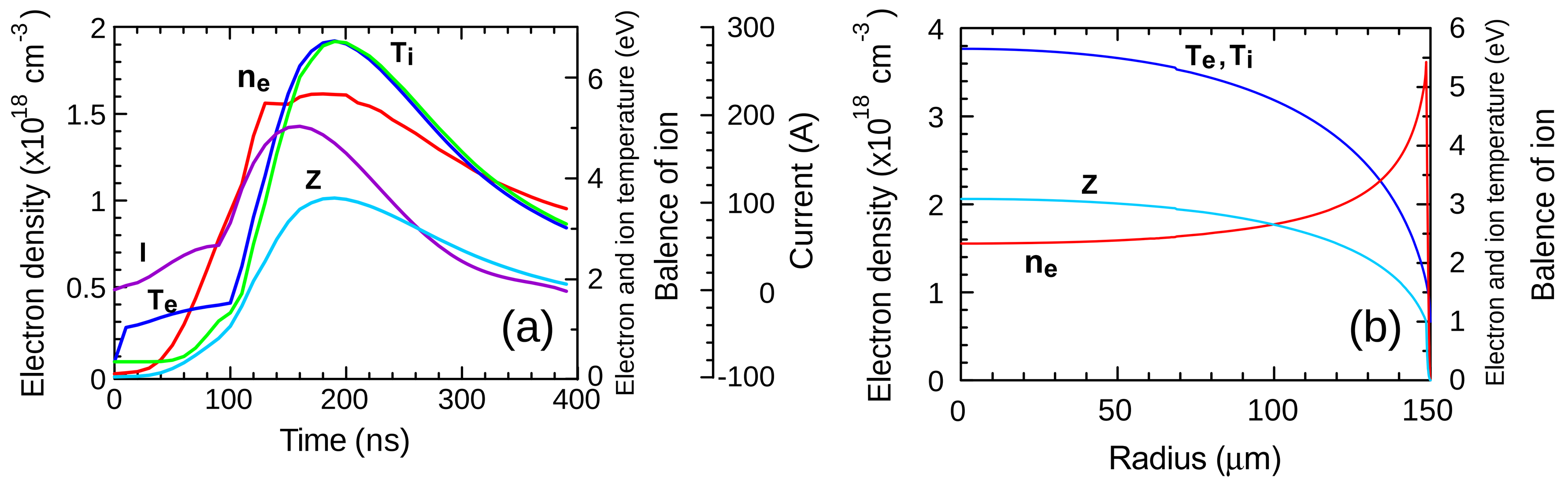


Fig. 5. (a) Calculated temporal evolution of the axial electron density n_e, ion and electron temperature T_i, T_e, mean degree of Ionization of argon plasma Z, and electric current I in the discharge as a function of time. (b) Calculated radial profiles of electron density n_e, ion and electron temperature T_i, T_e, and mean degree of ionization, Z, of the argon plasma at t = 150 ns.

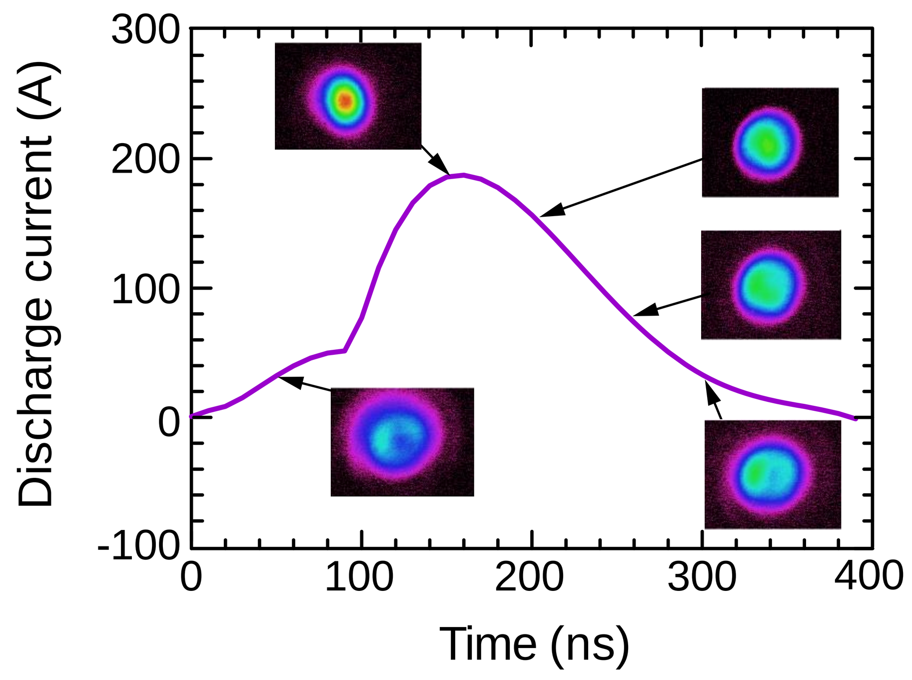


Fig. 6. Photographs of the transmitted laser profile at the capillary exit at different moments in time and the fitted discharge current (solid line). The fitted current profile was used in the MHD simulation.

4. Summary

We have investigated the preformed argon plasma waveguide produced in a long life alumina capillary.

- The electron density in the plasma channel was measured to be 1 x 10^{18} cm^{-3}.
- In the preformed plasma a maximum ion charge state of Ar^{3+} was deduced both from the observed visible emission spectra and from MHD simulation.
- The optimum timing of the laser pulse injection was around 150 ns for a discharge with peak current of 200 A.
- We showed that the laser propagates in a preformed argon plasma capillary with additional ionization.

References

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Acknowledgements

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